



Biofuels – The Current Industry and Future Prospects

John Ashworth

Team Leader, Biofuels Industrial
Partnerships

NREL, Golden, CO.



Why a National Program for Clean, Domestic Vehicle Fuels?

- National security concerns - diversifying our options in the face of rising fuel imports
- Reducing environmental pollution from vehicle emissions, particularly in urban areas
- Reducing greenhouse gas emissions
- Providing additional jobs and income in rural areas

Why Alternative Fuels?

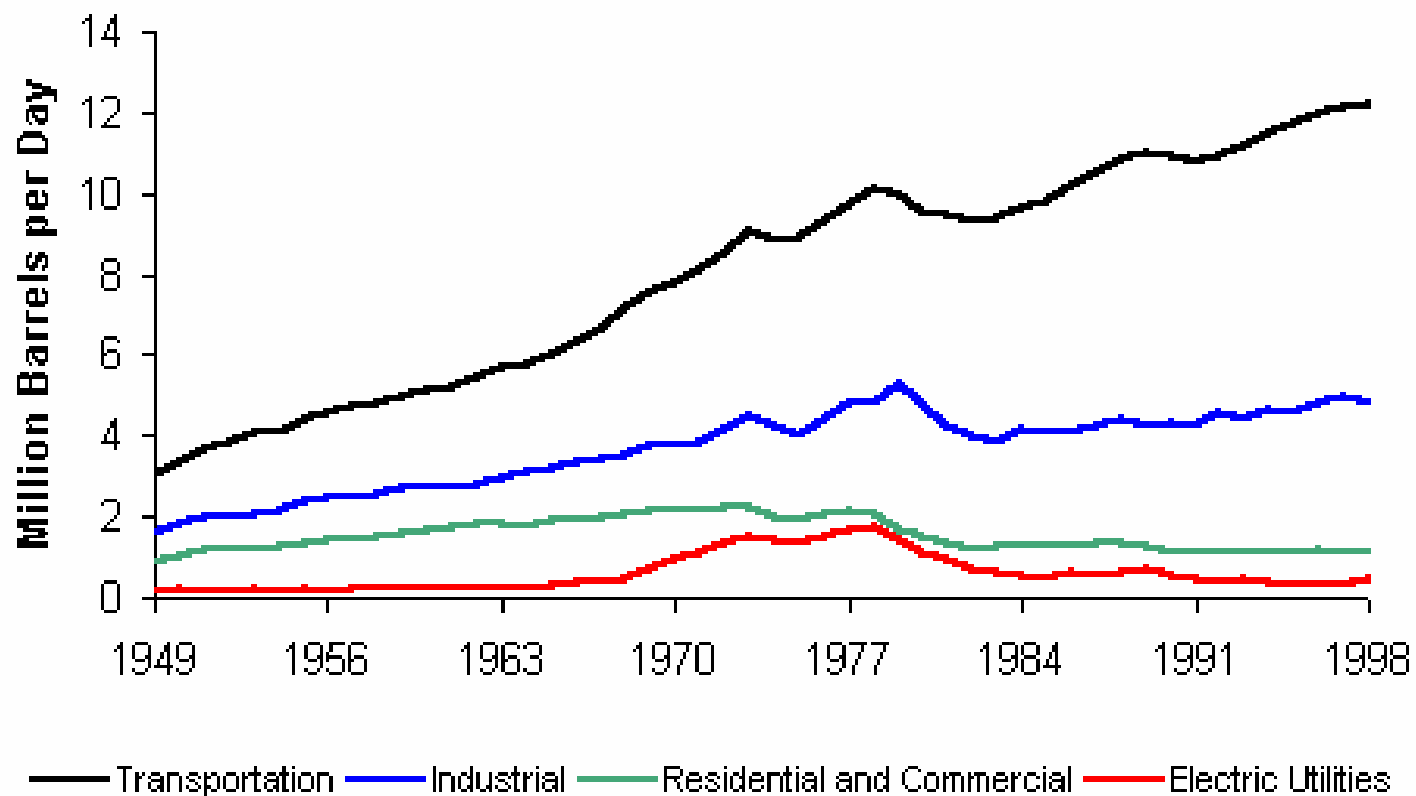
■ National Security

- ◆ 97% of transportation fuels are derived from fossil fuels
- ◆ More than 53% of US oil is imported
- ◆ Foreign oil demand will increase to 60% by 2005

■ Trade Balance

- ◆ Oil represents over 50% of all US imports
- ◆ 1973 oil embargo resulted in 10% GNP loss

Transportation Fuel Use is Key

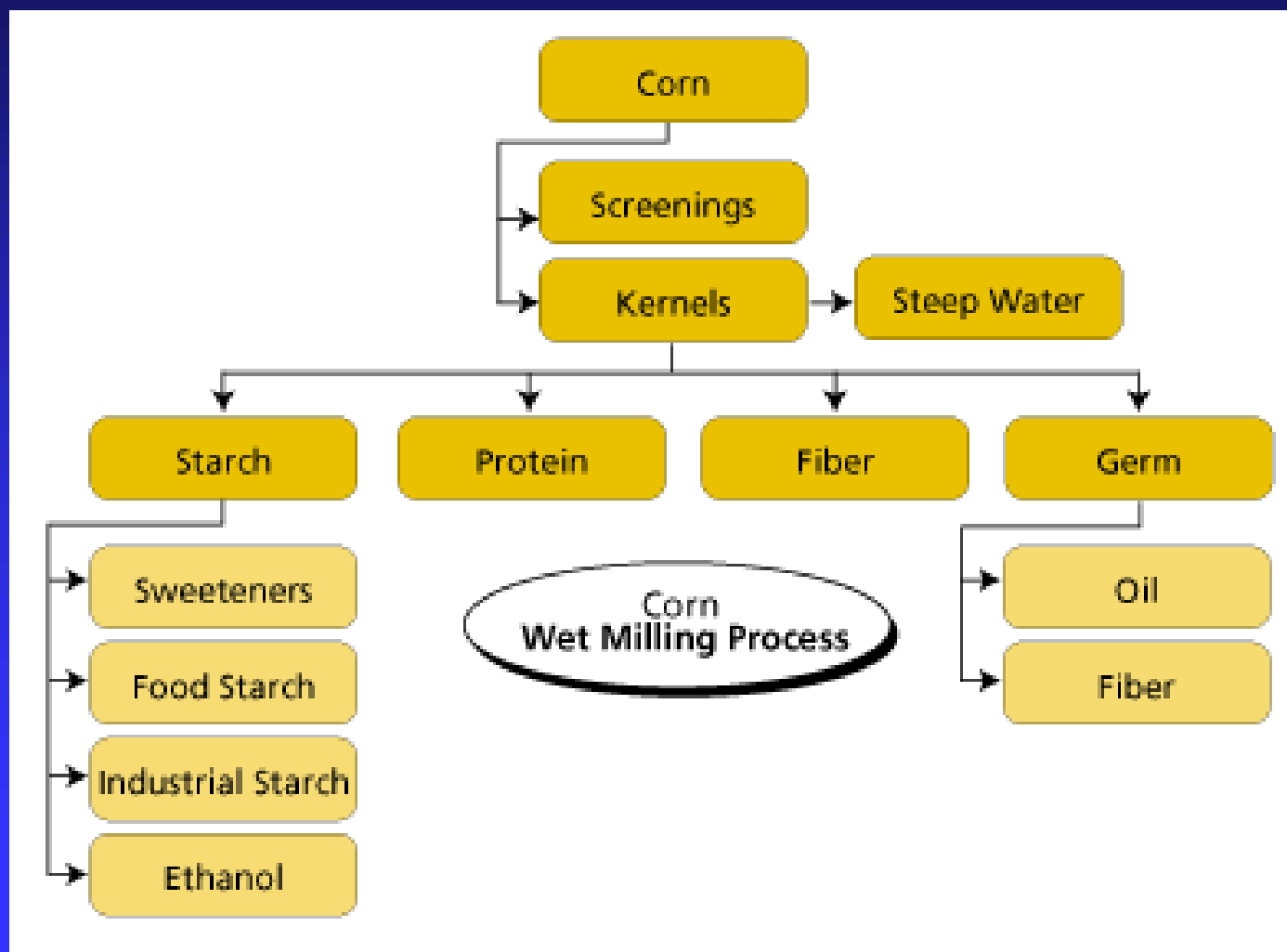


Why Ethanol?

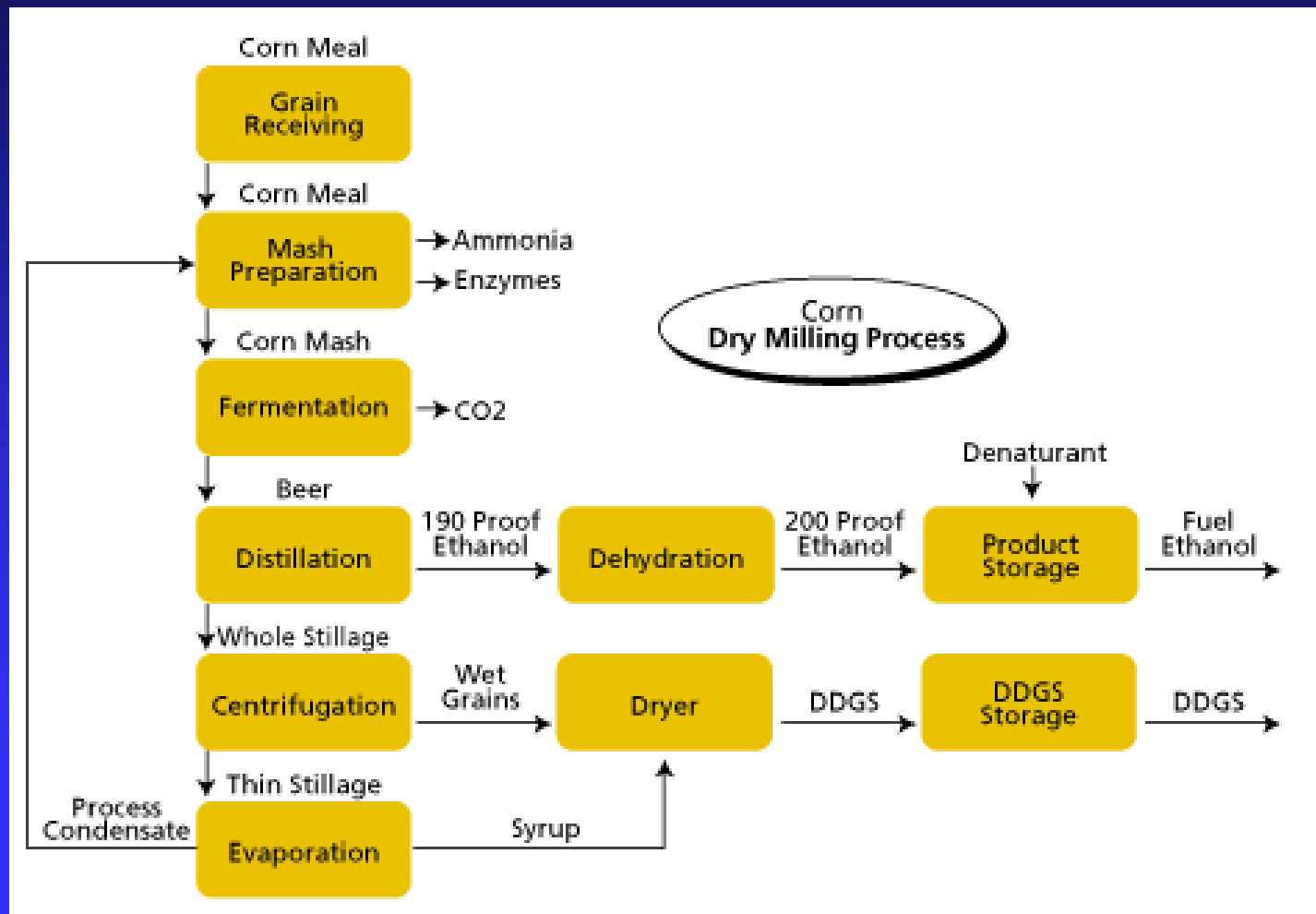
- Established Ethanol Industry
 - Available from domestic agriculture (corn fermentation)
 - Industrial interest increasing (oil companies)
 - Biomass ethanol will strengthen US farm economy
 - Biotechnology improvements will continue to reduce costs
 - Supporting industrial enzyme business well established
- Environmental Benefits
 - Oxygenates critical to attainment of CAA CO objectives
 - 39 regions in non-compliance
 - Biomass ethanol decreases CO₂ by 90% and SO₂ by 70% compared to RFG
 - ETBE improves combustion (all seasons)
 - Ethanol is a “clean” biotechnology-based technology



Wet Mills – the Current Biorefineries



Dry Mills – Simple Ethanol & Feed Plants

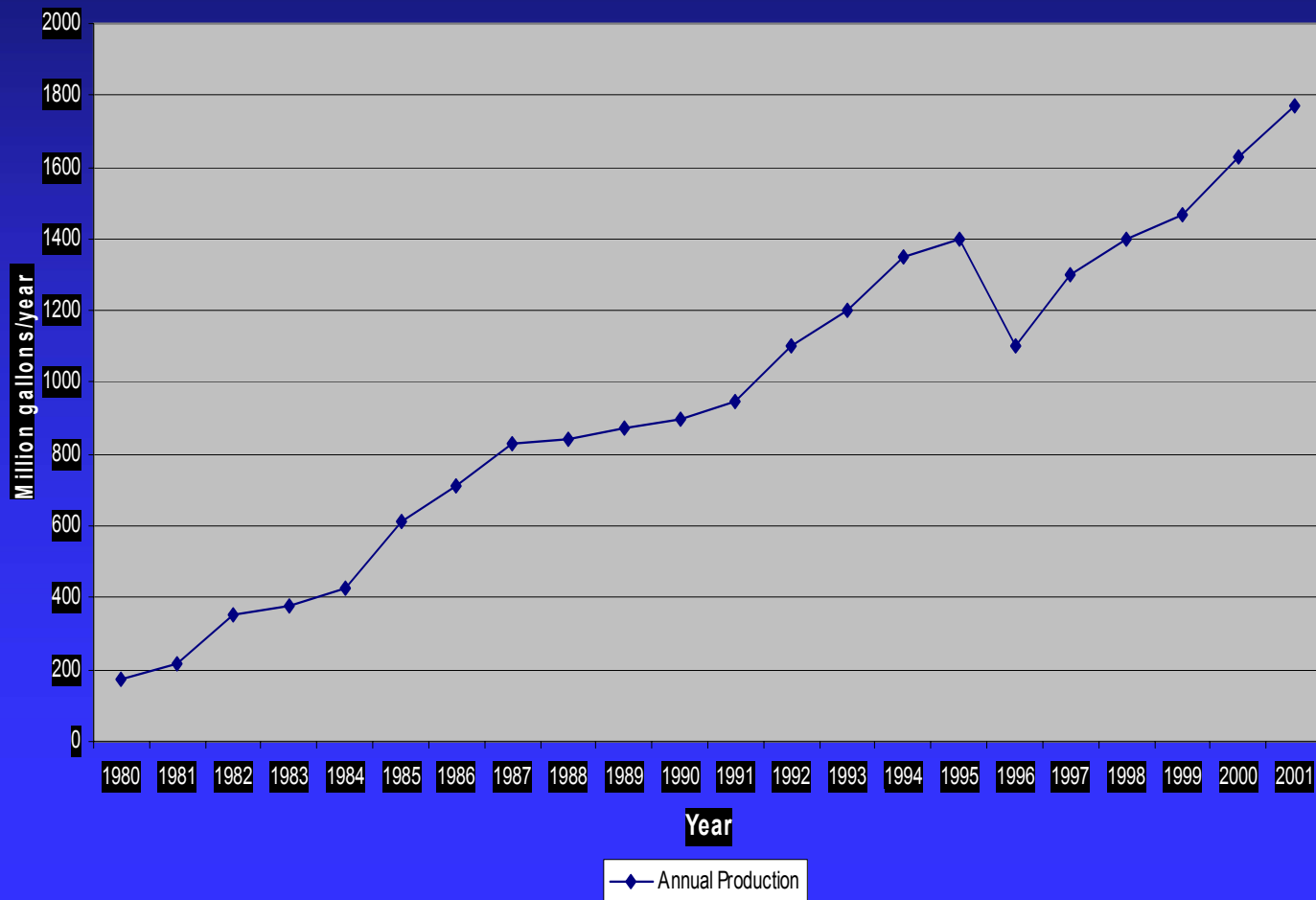


Key Ethanol Production Trends

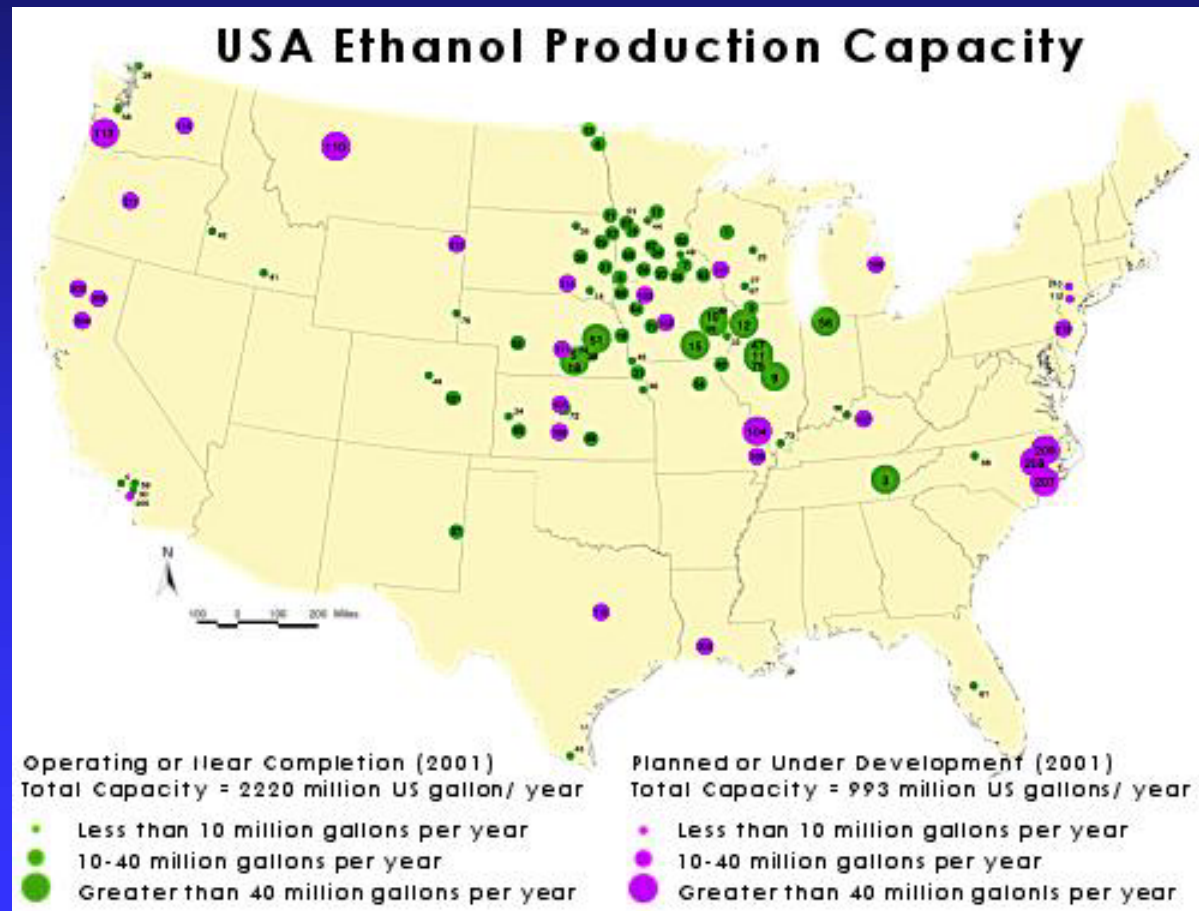
- U.S. production capacity is steadily rising
 - ◆ Adding capacity at existing plants
 - ◆ Building new plants
- ETOH production plants are getting larger
- ETOH plants are getting more efficient
- Feedstocks besides corn are being considered for ethanol fermentation

Ethanol Output has risen steadily

Historical U.S. Ethanol Production, 1980 - 2001



Geographic Distribution of ETOH Plants Growing Steadily



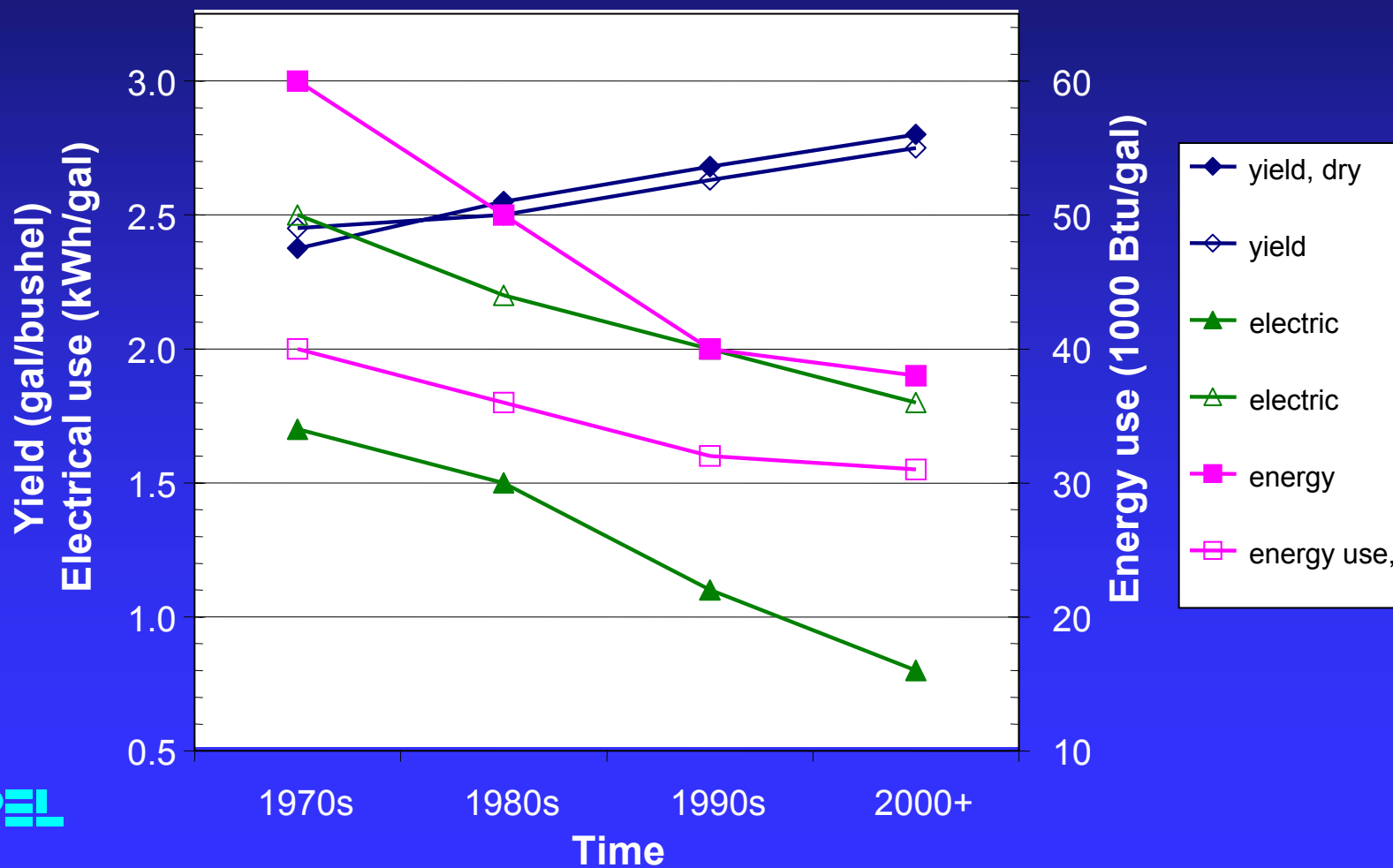
Dry Mills are Growing Larger

- Early plants were 5 – 8 million gallons
 - ◆ On-farm or near farm locations
- 1990s saw rise of 10 – 15 million gallon facilities
 - ◆ Many new generation farm coops involved as owners & feed suppliers
- 2001 – 40 million gallon turnkey plants becoming common

Growing Efficiency in Conversion of Grains to Fuel & Feed

- 2.5 gallons of ETOH per bushel of corn was a rule of thumb for years
- Now 2.7 or even 2.8 gallons per bushel
- Energy usage / gallon of ETOH has dropped dramatically
- Producers are looking for additional products besides ethanol and DDG

Growing Efficiency over Time



Benefits of Growing Ethanol Use

- Lower urban air pollution
 - ◆ Blending of ethanol into gasoline lowers toxic emissions by 30%, CO by 25- 30%, & smog formation by 20% or more
- Growing market for U.S. farm products
 - ◆ 2.0 billion gallons of ethanol will require about 750 million bushels of corn
- Rural employment and income
 - ◆ 195,000 rural jobs
 - ◆ \$4.5 billion additional farm income

Traditional Comestible Biomass Feedstocks

Corn



Sugar cane



Wheat



**Soybeans
Sugar beets
Cassava**

The Bridge to Corn Ethanol

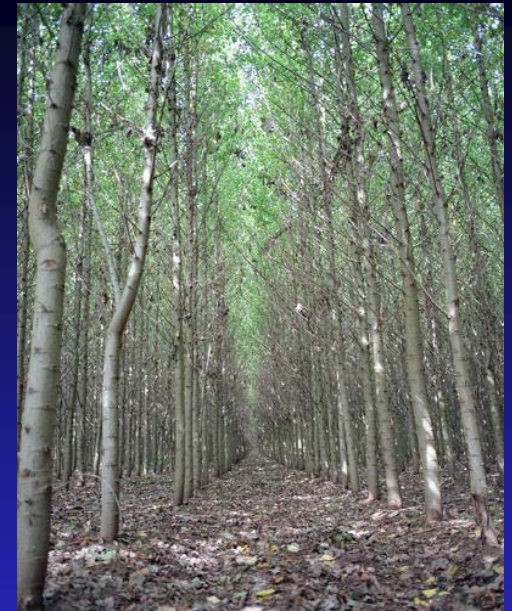
- Corn fiber (wet mills) or DDG (dry mills) can be pretreated, broken down with enzymes, and then converted to ethanol and other valuable co-products
- Research is underway at NREL and elsewhere to help starch ethanol industry increase ethanol production and maintain or increase value of byproducts

Bridge to Corn Ethanol (Cont.)

- NREL has been doing research on corn fiber and DDG since mid-1990s
- Aim is to increase ethanol yields of corn-based plants by fermenting of corn fiber
- Recently have started examining ways to
 - ◆ Break down fiber in DDG
 - ◆ Increase protein concentration in DDG
 - ◆ Locate and separate valuable by-products

Domestic Non-Food Biomass Feedstock Possibilities

- Agricultural residues
 - ◆ Corn Stover
 - ◆ Wheat and Rice Straw
 - ◆ Sugarcane bagasse
- Forestry wastes
 - ◆ Sawmill wastes
 - ◆ Forest trimmings
- Municipal solid wastes
- Dedicated energy crops



Corn Stover



Concentrated in 10 states
~80 million acres/yr
Average ~3 ton/acre/yr
Few economic uses



The Advantages of Corn Stover as a Renewable Feedstock

- 240 million tons or more of stover are grown in the U.S. each year
- If we used only 1/10 of total stover for alcohol, we could produce 16 billion gallons of ethanol or more than 9 times current U.S. ETOH production
- This would provide 10% of total U.S. gasoline consumption
- Sales of 10% of U.S. stover at \$10-20/ton would provide corn farmers with additional annual income of \$240 – 480 million

Stover Critical Success Factors

- Adequate supply of stover
- Ability to sustainably collect stover
 - ◆ Soil health
 - ◆ Environmental issues
 - ◆ Economic impacts of stover collection and use
- Ability to collect stover cost-effectively
 - ◆ Stover costs contribute significantly to ethanol cost

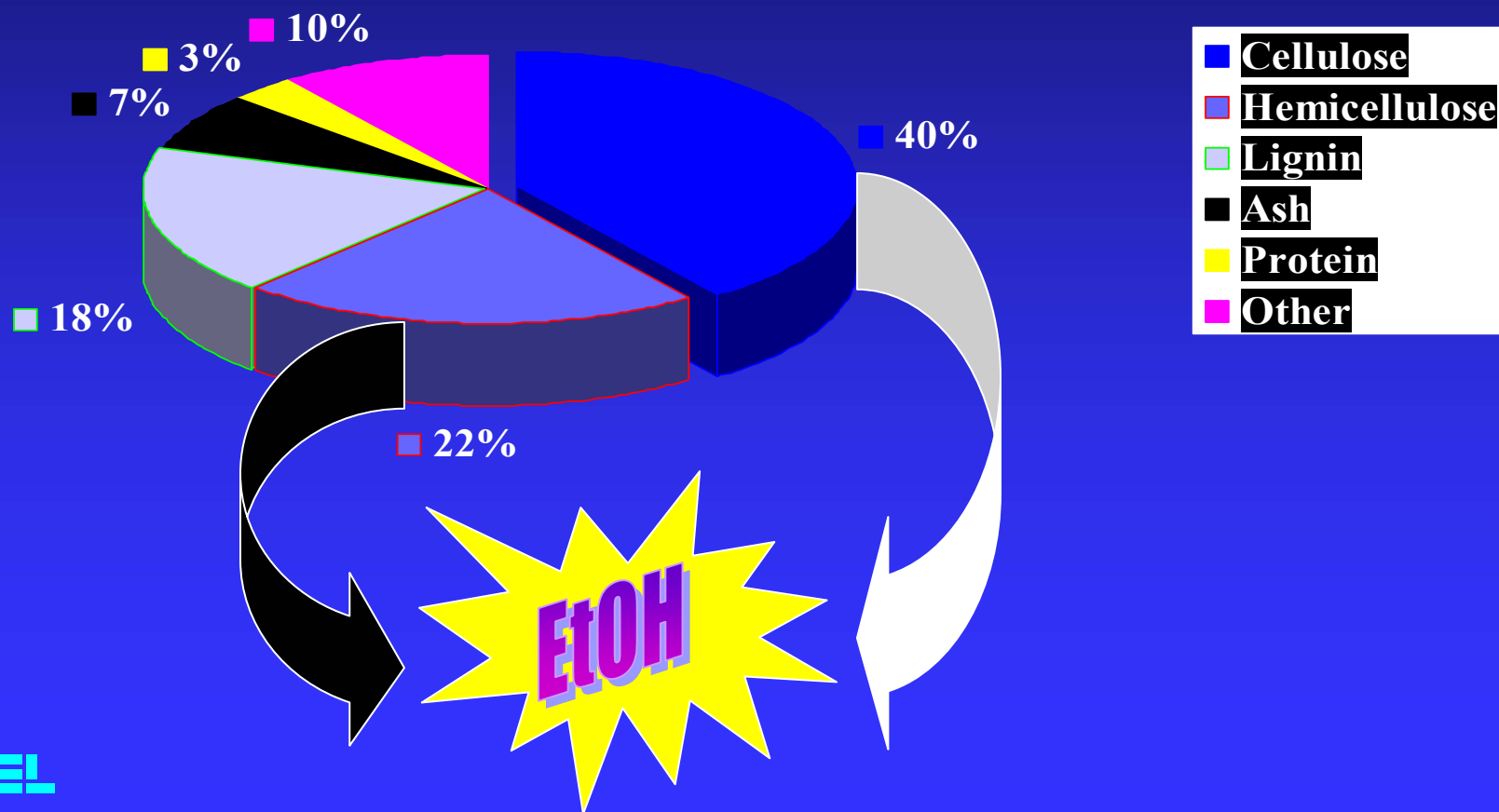


The Composition of Dent Corn

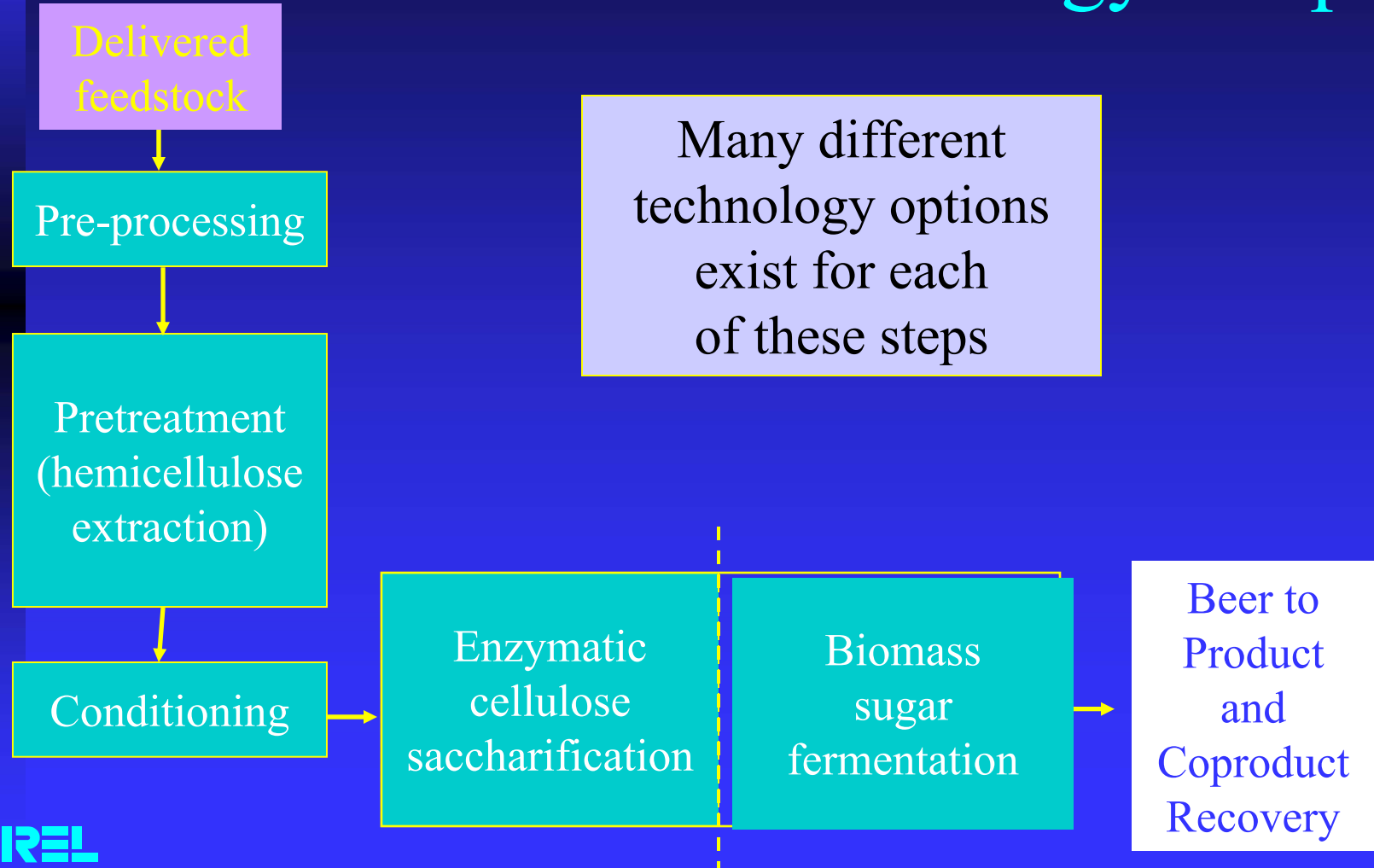
Component	% Dry weight
Starch	71.7
Pentosan (as xylose)	6.2
Cellulose + Lignin	3.3
Sugars (as glucose)	2.6
Protein	9.5
Oil	4.3
Ash	1.4



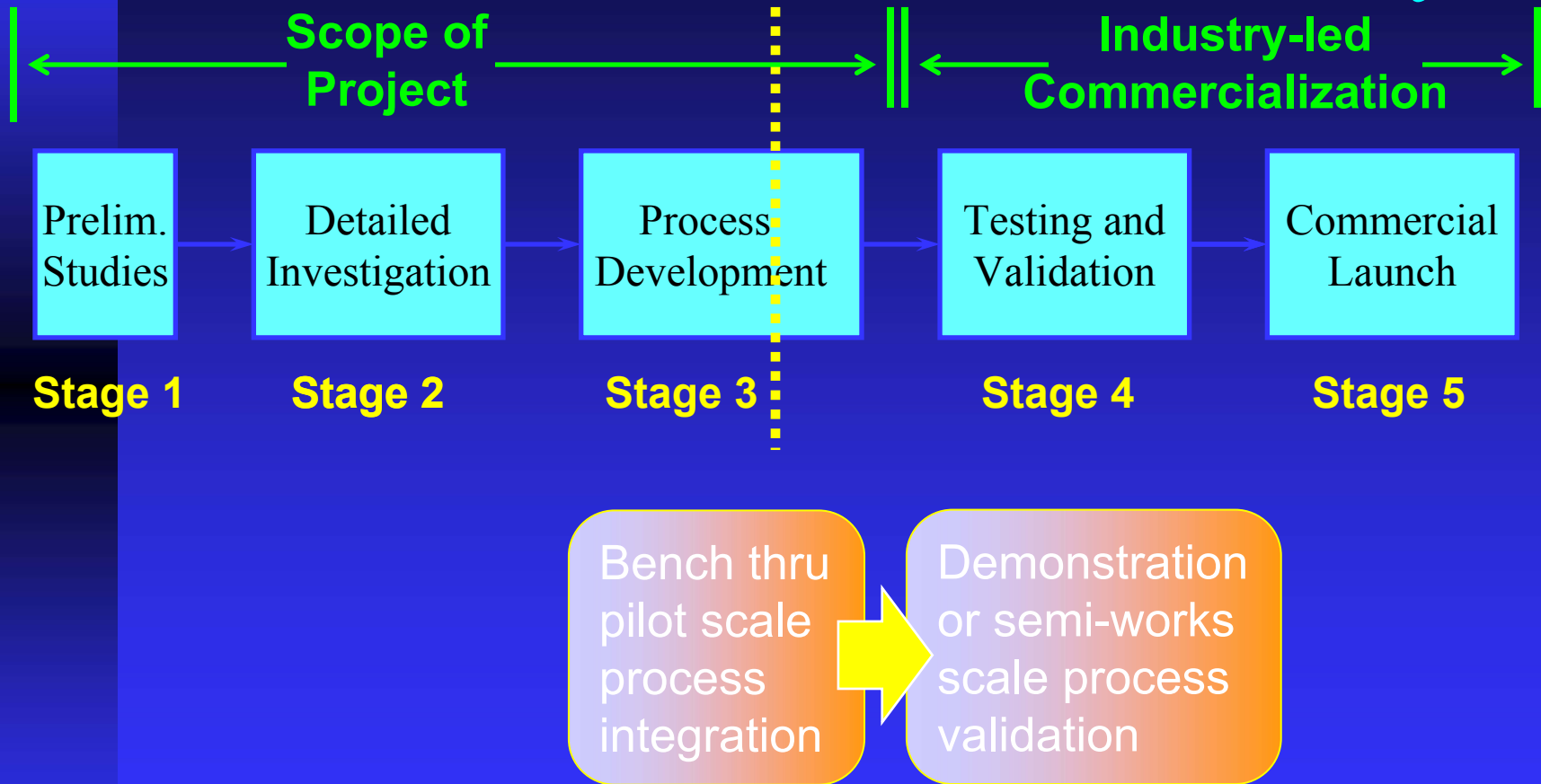
The Composition of Corn Stover



Ethanol & Co-Products from Ag Residues & Dedicated Energy Crops



Commercialization Pathway

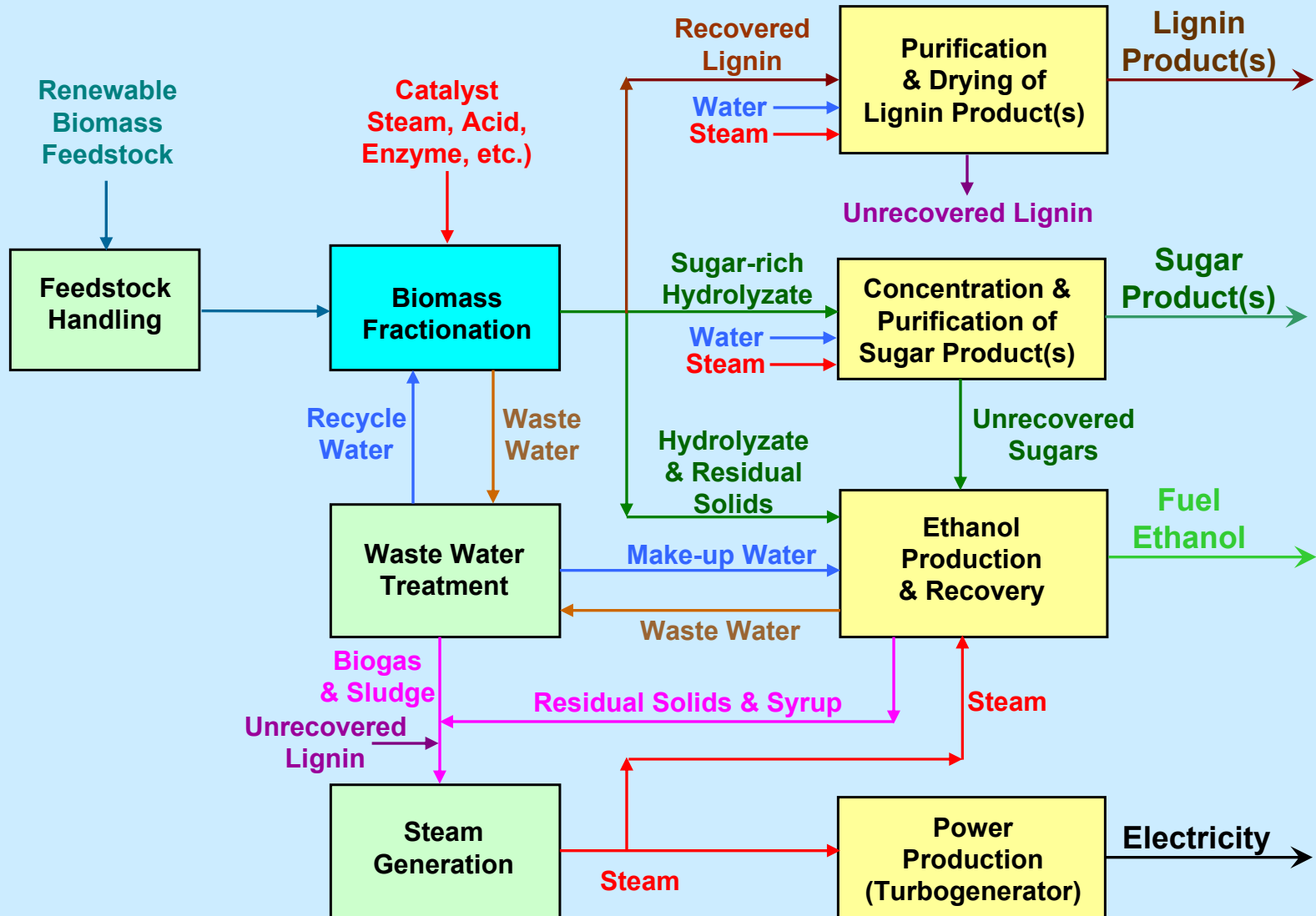


→ *Project success requires moving from Stage 3 to Stage 4!*

Corn Stover in our Enzymatic Conversion Process



The Future Sugar and Lignin Platform Biorefinery



The DOE Biofuels Program

Traditionally, the DOE Office of Fuels Development (DOE/OFD) has had 3 major research thrusts

- Development of conversion technologies
- Feedstock development – now transitioning to USDA
- Outreach and technology transfer – to industry, farm community and larger public

DOE/OFD Key Activities in the Past Several Years

- Pioneer Plants
- Partnership with Corn Ethanol Industry
 - ◆ Process improvement, corn fiber
- Enzyme Sugar Platform
 - ◆ Enzymes as enabling technology
- Valuable Co-Products
- 3rd generation Biorefinery

South Table Mountain Site



STM site totals 327 acres, 136 of which can be developed.

NREL total: 607 acres
(includes National Wind Technology Center)

Total capital equipment replacement value: \$75M

South Table Mountain Site - six facilities at 325,000 ft²
NREL total: eight facilities at 376,000 ft² *
Facilities replacement value: \$95M



**Does not include leased buildings*

NREL's Biotechnology Center has world class lab and pilot plant facilities

